

PATENT APPLICATION

ACTIVE DAMPER FOR STABILIZED MIRRORS

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CROSS-REFERENCE TO RELATED APPLICATIONS

Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

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INCORPORATION BY REFERENCE OF MATERIAL SUBMITTED ON A COMPACT DISC

Not Applicable.

COPYRIGHTED MATERIAL

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Not Applicable.

BACKGROUND OF THE INVENTION

Field of the Invention (Technical Field):

The present invention relates to dampening of belt modes of stabilized mirrors.

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Description of Related Art:

Gimbal assemblies are commonly employed in optical systems, such as forward looking infrared (FLIR) and laser based targeting and imaging systems, to position and/or stabilize optics, including mirrors. Precise pointing and stabilization of the optical line of sight is important to ensure line of sight accuracy, modulation transfer function, and so forth. Known gimbal assemblies include mirrors and/or lens assemblies that are controlled by belt drive systems, wherein a belt couples a belt drive motor situated on a gyro platform with a rotatable mirror of the gimbal assembly.

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Gimbal assemblies having belt drive systems are often used in applications where they are subjected to significant vibra-acoustic energy. Vibra-acoustic energy can disturb and/or degrade stabilization performance. In a gimbal assembly having a belt driven mirror, belt mode resonance causes amplification of mirror vibration that results in degradation of system performance. For example, mirror vibration can reduce the line of sight accuracy in a forward looking infrared radar/laser based optical system, further resulting in the degradation of targeting and/or imaging accuracy.

The vibra-acoustic energy causes the belt drive and mirror to vibrate at a frequency known as the belt modal frequency. For example, a belt modal frequency at around 400 hertz results in an approximate 52 decibel gain, which results in a substantial line of sight (LOS) disturbance of approximately 170 micro-radians root mean squared (RMS).

Most known systems use passive dampers to counter vibrations due to vibra-acoustic energy disturbance (e.g., vibra-acoustic disturbance torque). An exemplary passive damper can comprise a piece of tungsten steel mounted with rubber in shear, wherein the rubber has a high internal damping coefficient. Such passive dampers are also known in the art as inertial dampers or constrained layer dampers. However, passive dampers have several limitations. For example, passive dampers are limited in their ability to counter the effects of vibra-acoustic disturbance energy. Passive dampers typically provide only a 14 decibel improvement over undamped systems. Although passive dampers do provide some improvement, an undesirable amount of line of sight disturbance can still remain. In addition, passive dampers do not function efficiently, or at all, in cold environments. Notch filters may be employed to provide control loop stability but do nothing to attenuate LOS disturbance due to vibra-acoustics.

U.S. Patent No. 6,137,254, entitled "Active Vibra-Acoustic Damper", to Hughes, discloses one form of active damping, but lacks significant advantages of the present invention.

BRIEF SUMMARY OF THE INVENTION

The present invention is of an active damping method for a stabilized mirror, and a corresponding active damper apparatus, comprising: providing a tachometer measuring speed of a motor driving the mirror; employing compensation electronics receiving input from said tachometer and the motor; and employing drive electronics providing output to the motor. In the preferred embodiment, the motor comprises a DC torque motor (e.g., a limited angle tachometer), the tachometer comprises a limited angle tachometer, the electronics comprise an AC coupled rate loop (preferably wherein the electronics provide nearly zero phase shift at the lower and upper crossover frequencies of the damper control loop), and the method/apparatus operates on a stabilized mirror in a gimbal. Preferably, the method/apparatus dampens a belt mode, more preferably a belt modes at a frequency between approximately 240 Hz to 700 Hz, most preferably at or about 400 Hz, and most preferably provides at least approximately 70% dampening of a drive belt mode and wherein the method/apparatus is substantially insensitive to belt frequency. The method/apparatus is substantially insensitive to changes in temperature and does not affect operation of the mirror at frequencies at or below approximately one-half of a belt mode frequency.

Objects, advantages and novel features, and further scope of applicability of the present invention will be set forth in part in the detailed description to follow, taken in conjunction with the accompanying drawings, and in part will become apparent to those skilled in the art upon examination of the following, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The accompanying drawings, which are incorporated into and form a part of the specification, illustrate one or more embodiments of the present invention and, together with the description, serve to

explain the principles of the invention. The drawings are only for the purpose of illustrating one or more preferred embodiments of the invention and are not to be construed as limiting the invention. In the drawings:

5 Fig. 1 is a circuit diagram of the preferred compensation and drive electronics of the invention in conjunction with a DC torque motor and limited angle tachometer, particularly useful for damping an approximate 400 Hz belt mode;

 Fig. 2 is a functional block diagram of the gimbal servo with a 2:1 mirror drive in which the
10 invention is incorporated;

 Fig. 3 is a functional block diagram of the mechanism mass properties including the yoke assembly and the 2:1 mirror belt drive assembly of Fig. 2;

15 Fig. 4 is a functional block diagram of the active damper of Fig. 3 including the tachometer, compensation electronics, and motor and motor current amplifier; and

 Fig. 5 is a functional block diagram of the current loop of Fig. 4 including current loop compensation and motor characteristics.

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DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig. 1, the present invention is of an active damper **10** for stabilized mirrors (and a corresponding method), comprising a tachometer **12** measuring speed of the belt drive motor **14** and compensation and drive electronics **16**. The invention stabilizes the line of sight of a belt driven mirror
25 (e.g., in a gimbal assembly) when vibra-acoustic noise excites the belt mode resonance. Gimbal assemblies, for example, steer the line of sight of the mirror using a housing motor situated on a gyro platform, and an associated belt drive. As such, the active damper is configured to be insensitive to

lower frequencies, thereby allowing the gimbal assembly to move the mirror at a relatively slow constant rate. The active damper prevents the higher natural frequencies from exciting the mirror and destabilizing the line of sight. The invention is insensitive to variations in the dampened belt mode that are induced thermally or via variations in manufacturing.

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The active damper of the invention is an AC coupled rate loop (see Fig. 2) designed to provide damping to the belt mode only. It has no effect at frequencies less than half the belt mode frequency. The compensation actually provides nearly zero phase shift at the lower and upper crossover frequencies of the damper control loop. The primary purpose of the coupling is to provide AC coupling, thus eliminating any influence upon the gimbal at lower frequencies where LOS control is desirable for scanning and pointing.

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Fig. 1 shows in detail the preferred electronics for the present invention. The design provides excellent performance, enabling an approximate 6 microradian stabilization and an approximate 70% damping of a belt mode at approximately 400 Hz. The design is simple, permitting an electronics card with a very small footprint and able to use conductors already in place on most gimbals.

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Figs. 2-5 show functional block diagrams of the electronics of the invention in conjunction with the a limited angle DC torque motor and a limited angle tachometer. Figs. 2-5 are also useful in performing a Matrixx/Matlab simulation of the invention, permitting one of ordinary skill in the art to verify its utility and described and claimed.

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Although the invention has been described in detail with particular reference to these preferred embodiments, other embodiments can achieve the same results. Variations and modifications of the present invention will be obvious to those skilled in the art and it is intended to cover in the appended claims all such modifications and equivalents. The entire disclosures of all references, applications, patents, and publications cited above are hereby incorporated by reference.

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